

did the copper in the furnace, even at the end where the gas entered, show any sign of losing its metallic appearance.

Three results, obtained in August, 1892, were:—

August 8.....	2.31035
„ 10.....	2.31026
„ 15.....	2.31024
Mean	2.31028

To these may be added the results of two special experiments made to test the removal of hydrogen by the copper oxide. For this purpose a small hydrogen generator, which could be set in action by closing an external contact, was included between the two tubes of reduced copper, the gas being caused to bubble through the electrolytic liquid. The quantity of hydrogen liberated was calculated from the deflection of a galvanometer included in the circuit, and was sufficient, if retained, to alter the density very materially. Care was taken that the small stream of hydrogen should be uniform during the whole time (about 2½ hours) occupied by the filling, but, as will be seen, the impurity was effectually removed by the copper oxide.¹ Two experiments gave—

September 17 ...	2.31012
„ 20 ...	2.31027
Mean ...	2.31020

We may take as the number for nitrogen—

	2.31026
Correction for contraction ...	56
	2.31082

Although the subject is not yet ripe for discussion, I cannot omit to notice here that nitrogen prepared from ammonia, and expected to be pure, turned out to be decidedly lighter than the above. When the oxygen of air is burned by excess of ammonia, the deficiency is about 1/1000th part.² When oxygen is substituted for air, so that all (instead of about one-seventh part) of the nitrogen is derived from ammonia, the deficiency of weight may amount to ½ per cent. It seems certain that the abnormal lightness cannot be explained by contamination with hydrogen, or with ammonia, or with water, and everything suggests that the explanation is to be sought in a dissociated state of the nitrogen itself. Until the questions arising out of these observations are thoroughly cleared up, the above number for nitrogen must be received with a certain reserve. But it has not been thought necessary, on this account, to delay the presentation of the present paper, more especially as the method employed in preparing the nitrogen for which the results are recorded is that used by previous experimenters.

Reduction to Standard Pressure.

The pressure to which the numbers so far given relate is that due to 762.511 mm. of mercury at a temperature of 14° 85.3, and under the gravity operative in my laboratory in latitude 51° 47'. In order to compare the results with those of other experimenters, it will be convenient to reduce them not only to 760 mm. of mercury pressure at 0°, but also to the value of gravity at Paris.

The product of the three factors, corrective for length, for temperature, and for gravity, is 0.99914. Thus multiplied, the numbers are as follows:—

Air.	Oxygen.	Nitrogen.
2.37512	2.62534	2.30883

and these may now be compared with the water contents of the globe, viz. 1836.52.

The densities of the various gases under standard conditions, referred to that of distilled water at 4°, are thus:—

Air.	Oxygen.	Nitrogen.
0.00129327	0.00142952	0.00125718

With regard to hydrogen, we may calculate its density by

¹ Much larger quantities of hydrogen, sufficient to reduce the oxide over several centimetres, have been introduced without appreciably altering the weight of the gas.

² NATURE, vol. xvi. p. 512.

³ The thermometer employed with the manometer read 0° 15 too high.

means of the ratio of densities of oxygen and hydrogen formerly given by me, viz. 15.882. Hence

Hydrogen.
0.000090009.

The following table shows the results arrived at by various experimenters. Von Jolly did not examine hydrogen. The numbers are multiplied by 1000 so as to exhibit the weights in grams per litre:—

	Air.	Oxygen.	Nitrogen.	Hydrogen.
Regnault, 1847	1.29319	1.42980	1.25617	0.08948
Corrected by Crafts ..	1.29349	1.43011	1.25647	0.08988
Von Jolly, 1880	1.29351	1.42939	1.25787	—
Ditto corrected.....	1.29383	1.42971	1.25819	—
Leduc, 1891.....	1.29330	1.42910	1.25709	0.08985
Rayleigh, 1893	1.29327	1.42952	1.25718	0.09001

The correction of Regnault by Crafts (*Comptes Rendus*, vol. cvi., p. 1664) represents allowance for the contraction of Regnault's globe when exhausted, but the data were not obtained from the identical globe used by Regnault. In the fourth row I have introduced a similar correction to the results of von Jolly. This is merely an estimate founded upon the probability that the proportional contraction would be about the same as in my own case and in that of M. Leduc.

In taking a mean we may omit the uncorrected numbers, and also that obtained by Regnault for nitrogen, as there is reason to suppose that his gas was contaminated with hydrogen. Thus

	Mean Numbers.		
Air.	Oxygen.	Nitrogen.	Hydrogen.
1.29347	1.42961	1.25749	0.08991

The evaluation of the densities as compared with water is exposed to many sources of error which do not affect the comparison of one gas with another. It may, therefore, be instructive to exhibit the results of various workers referred to air as unity.

	Oxygen.	Nitrogen.	Hydrogen.
Regnault (corrected)	1.10562	0.97138	0.06949
v. Jolly (corrected)	1.10502	0.97245	—
Leduc.....	1.1050	0.9725	0.06947
Rayleigh	1.10535	0.97209	0.06960
Mean.....	1.10535	0.97218	0.06952

As usually happens in such cases, the concordance of the numbers obtained by various experimenters is not so good as might be expected from the work of each taken separately. The most serious discrepancy is in the difficult case of hydrogen. M. Leduc suggests (*Comptes Rendus*, July, 1892) that my number is too high on account of penetration of air through the blow-off tube (used to establish equilibrium of pressure with the atmosphere), which he reckons at 1 m. long and 1 cm. in diameter. In reality the length was about double, and the diameter one-half of these estimates; and the explanation is difficult to maintain, in view of the fact, recorded in my paper, that a prolongation of the time of contact from 4th to 30th had no appreciable ill effect. It must be admitted, however, that there is a certain presumption in favour of a lower number, unless it can be explained as due to an insufficient estimate for the correction for contraction. On account of the doubt as to the appropriate value of this correction, no great weight can be assigned to Regnault's number for hydrogen. If the atomic weight of oxygen be indeed 15.88, and the ratio of densities of oxygen and hydrogen be 15.90, as M. Leduc makes them, we should have to accept a much higher number for the ratio of volumes than that (2.0002) resulting from the very elaborate measurements of Morley. But while I write the information reaches me that Mr. A. Scott's recent work upon the volume ratio leads him to just such a higher ratio, viz. 2.00245, a number *a priori* more probable than 2.0002. Under the circumstances both the volume ratio and the density of hydrogen must be regarded as still uncertain to the 1/1000th part.

ELECTRICAL RAILWAYS.¹

ONE of the most striking of the many new departures in the practical application of electrical science, which made the Paris Exhibition of 1881 memorable, was a short tramway laid

¹ *Bulletin des Séances de la Société de Physique.*

² Friday evening discourse delivered at the Royal Institution by Dr. Edward Hopkinson on February 24.

down, under the direction of the late Sir William Siemens, from the Palais de l'Industrie to the Place de la Concorde, upon which a tramcar worked by an electric motor plied up and down with great regularity and success during the period of the Exhibition. Yet few of those who saw in this experiment the possibilities of a great future for a new mode of traction would have ventured to predict that within ten years' time, in the United States alone, over 5,000 electric cars would be in operation, travelling 50,000,000 miles annually, and carrying 250,000,000 passengers, or that electrical traction would have solved the problem of better communication in London and other large cities. Two years before the exhibition in Paris the late Dr. Werner Siemens had exhibited at the Berlin Exhibition in 1879 an experimental electric tramway on a much smaller scale, and his firm had put down in 1881 the first permanent electric railway in the short length of line at Lichterfelde, near Berlin, which, I believe, is still at work. In the same year Dr. William Siemens undertook to work the tramway, then projected, between Portrush and Bushmills, in the north of Ireland, over six miles in length, by electric power, making use of the water power of the Bush River for the purpose, an undertaking which I had the advantage of carrying out under his direction. It is no part of my object to-night to follow further the history of electric traction, which is so recent that it is familiar to all; but, in alluding to these initial stages of its development, I have desired to recall that it was to the foresight and energy of Dr. Werner and Dr. William Siemens, and their skill in applying scientific knowledge to the uses of daily life, which gave the first impulse to the development of the new electrical power.

The problem of electric traction may be naturally considered under three heads:—

- (1) The production of the electrical power.
- (2) Its distribution along the line.
- (3) The reversion of electrical into mechanical power, in the car motor or locomotive.

The first of these here in England at any rate is dependent upon the economical production of steam power, although there are essential points of difference between the conditions under which steam power is required for electric traction purposes and for electric lighting. But in Scotland and Ireland and in many countries abroad there is abundant water power, now only very partially utilised. The Portrush line is worked in part by water and in part by steam power, but in the Bessbrook and Newry Tramway (of which there is a working model on the table) water power is exclusively used.

A few experiments will show that the demand for power on the generating plant is greatest at the moment of starting the car or train, when in addition to the power required to overcome the frictional resistances power is also required to accelerate the velocity. Thus, if instead of a single car there are a number of trains moving on the one system, and it so happens that several are starting together, the demand made upon the generating plant may at one moment be three or four times as great as that made a few seconds after. This is shown in the diagrams which exhibit the variation of current supplied by the generators on the City and South London Railway, with eight trains running together, the readings being taken every ten seconds. The maxima rise as high as double the mean; thus the generating plant must be capable of instantly responding to a demand double or even treble the average demand upon it.

In electric lighting it is true there is not less variation between the maximum demand and the mean taken during the ordinary hours of lighting, but it is only in the event of sudden fog that the probable demand cannot be accurately gauged beforehand, and provided for by throwing more generators into action. Thus in a lighting station each generator may be kept working approximately at its full load, and therefore under conditions of maximum economy, whereas in a traction station the whole plant must be kept ready to instantaneously respond to the maximum demands which may be made upon it, and must therefore necessarily work with a low load factor, and consequently with diminished economy. So important is the influence on cost of production of the possible demand in relation to average demand, that the Corporation of Manchester under their order for electric supply, have decided upon the advice of their engineer to annually charge a customer £3 per quarter for each unit per hour of maximum supply which he may require, in addition to 2d. per unit for each unit actually consumed, *i.e.* for being ready to supply him with a certain amount of electrical power if required to do so, they charge an

additional sum equivalent to the charge for its actual consumption for 1440 hours.

In one respect water power has an economic advantage over steam power, because although steam engine and turbine alike work with greatly reduced efficiency at reduced loads, when the turbine gates are partially closed and the water restrained in the reservoir, it is not subject to loss of potential energy, whereas the energy of the steam held back by the valves of the engine suffers loss through radiation and condensation.

At Bessbrook the turbine and generator dynamo combined yield 60 per cent. of the energy of the water as electrical energy available for work on the line, but when the load is reduced to a third of the full load the efficiency is reduced to 33 per cent. So on the City and South London line a generator engine and dynamo will yield, when working at their full load, 78 per cent. of the indicated horse-power as useful electrical power, but at half load the efficiency falls to 65 per cent. Notwithstanding these conditions the generator station of the City and South London line is producing electrical energy at a cost of 1.56d. per Board of Trade unit, which is less than the annual average cost of production of any electric station in England, with the single exception of Bradford, which has the advantage both of cheap coal and cheap labour. In output it is the largest of any Electric Generating Station in England, the total electrical energy delivered in 1892 being 1,250,000 Board of Trade units, the second on the list being the St. James and Pall Mall with 1,186,826 units.

Let us pass now to the consideration of the distribution of the electric power along the line. I have equipped the three model tracks before you with three different kinds of conductors. In two of them the rails of the permanent way, which are necessarily uninsulated, are made use of for the return current. This plan, with I believe the almost single exception of the Buda Pesth Tramway, has been universally adopted with the object of saving the cost of a return conductor; but it is doubtful whether such an arrangement can be considered final, for it must necessarily create differences of potential in the earth, which already in some instances have had disturbing effects upon our observatories, or upon our telegraph and telephone systems. It appears to be probable in the more or less distant future that the use of the earth for the passage of large current will be guarded by legislation; and that it will be reserved for the more delicate and widely extended operations of telegraphy and telephony. These disturbances may of course be easily avoided by the use of an insulated conductor for the return circuit. In the case of conductors which are in such a position that contact may be made from them to the ground through the body of a horse or some other animal coming into contact with them, there is another strong argument for an insulated return, as many animals, and notably horses, are far more sensitive to electric shock than man. It is not perhaps well known, but still a fact, that a shock of 250 volts is quite sufficient to kill a horse almost instantaneously.

The first model has a single overhead conductor with return by the rails; but in place of a single fishing-rod collector or trolley to take the current from the overhead wire there are fixed on the car two rigid bars, one at each end, which slide along the under surface of the wire and make a rubbing contact against it. This system, devised by Dr. John Hopkinson, has the advantage that there is less difficulty in maintaining contact on uneven roads or on curves, and that the catenaries of the suspended wire may be hung with greater dip, and therefore with less tension. Again, the double contact obviates the frequent breaks and consequent sparking of a single trolley system. The second model shows the system adopted on the City and South London line, and more recently followed on the Liverpool Overhead line, of a conductor of channel steel, upon which collectors fixed to the locomotives make a sliding contact. The third track shows an overhead system like the first, but with an insulated return in place of return by the rails.

The characteristic feature of an electric motor is that it delivers us the mechanical power we require directly in the form of a couple about an axis instead of in the form of a rectilinear force, as is the case with steam, gas, or air engines, which must be reduced to a rotary form by connecting rod and crank. Thus it is possible to sweep away all intermediate gear, and to arrive at once at the simplest of all forms of a traction motor, consisting of but one pair of wheels fixed on a single axle with the armature constructed directly upon it, with its magnets suspended from it and maintained in their position against the

magnetic forces acting upon them by their weight. Such a locomotive is shown in the third model before you. So far as I am aware, a locomotive of such simplicity as this has never been constructed for practical work, but on the City and South London line the armatures of the motors are placed directly on the axles and the magnets, suspended partly from the axles and partly from the frame.

The second model is an exact reproduction of the locomotives on the City and South London line, but with a different arrangement of motors. Here both armatures are included in the same magnetic circuit, and both magnets and armatures carried on the frame of the locomotive and not on the axles. The armatures are geared to the axles by diagonal connecting rods, the axle boxes being inclined, so that their rise and fall in the horn blocks is at right angles to the connecting rods. This design, which is due to the late Mr. Lange, of Messrs. Beyer, Peacock & Co., allows of the motor armature being placed on the floor level of the locomotive, and so more easily accessible.

This model will serve to show some of the characteristic features as well as some of the characteristic defects of an electric motor as such. But in order to show these clearly I may refer for a moment to the general theory of a motor. It is easily shown that in a series wound motor the couple or turning moment on the axle is a function of the current only, and independent of the speed and electro-motive force. Again it follows from Ohm's law that the current passing through the motor multiplied by the resistance of the magnet and armature coils is equal to the difference between the electro-motive force at the terminals of the motor and the electro-motive force which would be generated by the motor, if it were working at the same speed as a generator of electricity, that is to say the difference between the electro-motive force at the terminals and what is called the "back" or "counter" electro-motive force of the motor. Hence if the terminals of the motor be coupled direct to the line at the moment of starting when the motor is still at rest, the current will be very great and its power entirely absorbed in the coils of the armature and magnets, but the turning moment will then be a maximum. The motor then begins to move, part of the power being spent in overcoming frictional resistances and part in accelerating the train. A back electro-motive force is then set up, increasing as the speed increases, and causing the current to diminish until finally a position of equilibrium is established, when the speed is such that the back electro-motive force together with the loss of potential in the coils of the motor is equal to the potential of the line. But in practice the mechanical strength of the motor, and the carrying power of its coils, as well as the limited current available from the generators makes it necessary to introduce resistances in circuit with the motor to throttle the current and to reduce it within proper limits. It is to this point I desire to draw attention, that in traction work when starting the motor resistances must be introduced, which, with the resistance of the motor itself, at the moment of starting, absorb the whole power of the current, reducing the efficiency of the motor to nil, and which continue to absorb a large percentage of the power, until the condition of equilibrium is established. This is the great defect in electric motors for traction work, and its importance can be shown very clearly by reference to the work done on the City and South London line. There the motors when working with their normal current have an efficiency of 90 per cent., but the actual all-round efficiency of the locomotives as a whole is 70 per cent. only, so that the loss in starting is equal to 20 per cent. of the whole power. Of course in some respects the City and South London line is exceptional in that a start is made every two or three minutes. Various devices have been suggested with a view to diminishing this waste of power in starting an electric motor, but none entirely meet the case. Thus if the locomotive or car has two motors, these can be coupled in series at the start, and subsequently thrown into parallel, thereby doubling the tractive force with a given current, or for the same tractive force reducing the loss of power by three-fourths. When through the increase of speed of the motor the back electro-motive force balances the electro-motive force of the line the speed can be increased by diminishing the magnetic field by reducing the effective coils on the magnets, but this device does not give any assistance at the lower speeds, as the magnets ought to be so wound as to be high on the characteristic curve, or nearly saturated, with the normal current, and it is therefore not possible to obtain any increased intensity of field, by increasing the convolutions

of the magnet coils. If it were possible to use alternate current motors for traction work the difficulty could at once be met by introducing a transformer in the circuit, and placing the motor in its secondary. The effective convolutions of the secondary circuit on the transformer could then be varied as the speed increases in such wise that the electro-motive force of the line is balanced by the back electro-motive force of the motor and the fall of potential due to the resistance of the motor coils, so avoiding all need for resistances.

The City and South London line has enabled experiments to be made on the efficiency of the railway system as a whole, taking into account the loss of power in the generators, on the line, and in the motors, and in the resistances of the locomotives. The loss in the line is about eleven per cent. of the power generated, and the efficiency of the locomotives as a whole is, as I have shown, 70 per cent.; thus the electrical efficiency of the entire system is 62 per cent. The trains weigh with full load of 100 passengers about forty tons, and the average speed between stations is 13.5 miles per hour. The cost of working, including all charges, during last half year was 7.1d. per train mile, of which 4.7d. represents the cost of production of the electric power, and 2.4d. the cost of utilising it on the locomotives. It is perhaps hardly a fair comparison to compare the cost of working such a line as the South London line with the cost of steam traction on other lines, inasmuch as steam could not possibly be used in the tunnels, only 10' 6" diameter, in which this line is constructed, but the comparison is not uninteresting. Take the Mersey Railway, where the gradients and nature of the traffic are similar. On the Mersey Railway the locomotives weigh about 70 tons, and the train, which is capable of carrying about 350 passengers, 150 tons. According to the published returns of the company the cost of locomotive power is 1.4d. per train mile, i.e. double the cost on the South London line, but for a train weighing between four and five times as much but capable of carrying only $3\frac{1}{2}$ times the number of passengers; thus the cost of steam traction per ton mile of train is about half that per ton mile of train for electric traction. But it is not on the cost per ton mile that the success of a passenger line depends. The real basis of comparison is the cost per passenger mile, and here electric traction has great advantage over steam, as the dead weight of the electric motor is small compared with the dead weight of steam locomotives of the same power, and with electric motors the trains can be split up into smaller units at but slightly increased cost, so permitting a more frequent service. We cannot expect, therefore, that electric traction with our present knowledge will take the place of steam traction on our trunk lines; but it has its proper function in the working of the underground lines now projected for London, Paris, Berlin, and Brussels, and other large towns, and also I think on other urban lines, for example, on the Liverpool Overhead Railway, where trains of large carrying capacity are not required, but a frequent service is essential; and finally, also on those short lines, whether independent or branches of the great trunk lines where water power is available. When I undertook the construction of the Bessbrook line it was a condition that the cost of working should be less than the cost of working by steam, a condition which the first six months of working showed to be successfully fulfilled. When Messrs. Mather and Platt undertook the construction of the electric plant for the City and South London Railway, they guaranteed that the cost of traction for a service of 8247 miles per week as actually run should not exceed 6.3d. per train mile, exclusive of the drivers' wages. Their anticipations have been more than realised, the actual cost being 5.1d. per train mile only. There are, however, other projects both in America and on the continent for electric railways on which the special feature is to be an enormously high speed of travel, speeds of 150 and even 200 miles per hour being promised. With a steam locomotive, involving the reciprocating motion of the piston and connecting rod, such speeds are probably unattainable, but they may be realised in the purely rotary motion of an electric motor. But at such high speeds as these the power required to overcome the air resistance is of special consideration. Probably up to speeds of 750 miles per hour, or even to higher limits still, the ordinary law of air resistance holds good, as the rate of disturbance is still less than the velocity of waves in air, but above these limits we leave the regions of ordinary locomotion and enter rather into the field of projectiles. Assuming, however, that the ordinary laws of air resistance do hold good, I calculate that the power required to propel an ordinary train 200 feet long at 200 miles per hour against the

resistance of air alone, apart from the frictional resistances, would not be less than 1700 horse power. Though there is nothing to prevent the construction of electric locomotives capable of developing this or even greater power, the strength of the materials at present at command will set a limit to the speeds which may be obtained.

In order that the engineer may realise the imperfection of all his works, it is well for him to be constrained from time to time to contemplate the amount of energy involved in his final purpose compared with the energy of the coal with which he starts. I have endeavoured to put before you to-night the losses that occur and the reasons for them, in some steps of the complex machine which constitutes an electric railway, so in conclusion I will draw your attention to the ultimate efficiency of the machine, starting with the coal and ending with the passenger carried through space. The diagram on the wall, starting with the familiar 12,000,000 foot-pounds, the energy of a pound of coal, shows the loss in each step, supposing it made with the most economical appliances known to the engineer, first in the boiler, then in the steam engine, generator dynamo, conductors, locomotives, in the dead weight of the train, till finally we arrive at the energy expended on the passenger himself, which we find to be 133,000 foot-pounds, or but little more than 1 per cent. of the energy with which we started. It is true indeed that transportation is a more economical process than lighting with incandescent lamps, in which the final efficiency is about one-half per cent., but whether in lighting or in traction, when we consider that ninety-nine parts are now wasted for one part saved, we may realise that the future has greater possibilities than anything accomplished in the past.

HAIL STORMS.¹

SOME recent thunder and hail storms were so violent that they call for more than a passing notice, not only on account of their severity, but also because they are well marked phenomena in our weather. The district in which they were most severe is that around Narrabri, and the weather map for the day indicated this district as one in which storms would probably manifest great intensity. The places from which the best accounts have reached me are Narrabri, Avondale, thirty miles due north of Narrabri, and Tulcumbah, fifty-seven miles south-east of Narrabri.

The Sydney weather chart at 9 a.m. on October 13, the day of these storms, shows us that there was but little difference in pressure all over Australia. To the west of the overland telegraph line it was slightly higher, over western New South Wales and Queensland lower, and higher again over the East Coast, in which the isobars clearly outline the area of relatively low pressure, and the kinks in them indicate disturbed conditions, local short-lived storms, and before the day was over the inference from the state of pressure was fully justified, for storms of extreme violence occurred over the area; storms which swept down great forest trees two and three feet in diameter. What this means in wind velocity I am unable to say, the trees are eucalypts, and therefore the wood is hard and very strong, but they were treated as if they were reeds, and their strength was as nothing compared with the force of the wind.

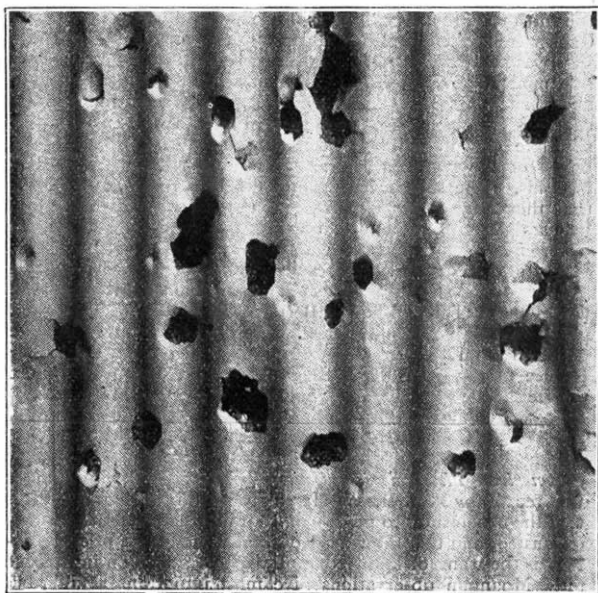
These storms are common enough, but owing to the sparse population they seldom pass over towns or dwellings. In this instance such has been the case, and in the future as population increases similar cases must increase in number, for the storms are abundant, indeed these storms form a well-marked feature of our summer weather. As a rule they are disconnected, and the most violent part of the wind covers but two hundred or three hundred yards wide, and travels along with great rapidity, leaving a narrow line of destruction in its wake.

On the day in question heavy storms were reported at Goodooga, Armidale, two hundred and forty miles south-east of Goodooga, and at Grafton one hundred miles north-east of Armidale. Storms which seem to have been quite disconnected, for the earliest time was at Grafton, and as a rule they come from the west; these are spoken of as severe storms, but were evidently not specially remarkable, nothing to compare with those in the Narrabri district to which I wish to direct your attention. Unfortunately, data for determining the rate of progress is not available, although that as to the intensity of the storms is abundant. I may mention that three days before these storms, that is on

October 10; a similar storm passed over from Wilcannia to Sydney, a distance of four hundred and eighty miles, at the rate of fifty-five miles per hour; and I have before traced one over the same part of the colony, the rate being fifty-seven miles per hour, but we have not traced a sufficient number to determine an average rate.

As to the velocity of the wind along the line of damage in these storms, we have no actual anemometer results, so far we have not had one which passed over one of the anemometers, but judging from the damage done to large and solid trees, two and even three feet in diameter, it cannot I think be less than one hundred and forty or one hundred and fifty miles per hour.

We may now turn to the storms in the Narrabri district. The storm reached Narrabri at 6.15 p.m., and the postmaster reports that the storm which approached Narrabri from north-west was accompanied by thunder and lightning, but no hail. The wind, however, seems to have been of hurricane violence, trees two feet in diameter were torn up by the roots, limbs twelve inches through were snapped off short, a brick factory completely ruined, roofs, sign-boards, and everything that the wind could move went flying; in the language of the local newspaper, "substantial brick buildings came tumbling in all directions, the



Photograph of iron perforated by hail.

air was full of iron tubs, galvanised iron, and tins of every description."

In the district south of Narrabri the storm was even more severe. At Tulcumbah Station, fifty-seven miles south-east of Narrabri, at 8 p.m. on October 13, a violent thunder and hail storm broke over the homestead. It lasted half an hour, and Mr. A. D. Griffiths, my informant and manager of the station, says, "I measured some of the hailstones, six and a half inches in circumference; this was fifteen or twenty minutes after the storm, and I think I did not get the largest. Next morning I found that nineteen sheep had been killed by the hail, also birds, kangaroo-rats, and other animals were found lying dead in all directions. All the windows exposed to the storm were broken, and the galvanised iron roofing is dented from end to end, and many sheets cut through: in several cases the hailstones went through the iron; in one sheet I found thirty holes, and in another more than sixty. The bark of the trees in the storm track was all battered by the hail, and the fences and buildings bore traces of the impact of these great lumps of ice. The stones were generally triangular or conoidal in form, many having an uneven surface, which looked as if it had been formed from frozen drops of water collected into masses; others had an opaque snow-like centre, perhaps the majority were like this, the remainder being like clear ice. It was only the larger stones that were irregular as described, the smaller ones were generally rounded."

At Avondale, thirty miles north of Narrabri, my informant,

¹ Read by H. C. Russell, F.R.S. before the Royal Society of N.S. Wales, November 2, 1892.